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1 CONDUCTIVE POLYMER DEVICE AND METHOD OF
2 MANUFACTURING SAME
3

4 BACKGROUND OF THE INVENTION

5 The present invention relates generally to the field of electronic devices. More
6 specifically, this invention relates to positive temperature coefficient (PTC) devices that are
7 designed for overcurrent protection and can be surface mounted in printed circuit board (PCB)
8 applications.

9 It is well known that the resistivity of many conductive materials changes with
10 temperature. For example, the resistivity of a PTC material increases as the temperature of the
11 material increases. Examples of such a material are organic polymers, made electrically
12 conductive by dispersing conductive fillers therein. These polymers generally include
13 polyolefins such as polyethylene, polypropylene and ethylene/propylene copolymers.
14 Conductive fillers include carbon black and metal powders.

15 Typically, a conductive polymer PTC device comprises a layer of conductive polymer
16 PTC material sandwiched between upper and lower metal foil electrodes. The prior art includes
17 single layer devices and multilayer devices, the latter comprising two or more conductive
18 polymer layers separated by one or more internal metal foil electrodes, with external metal foil
19 electrodes on the upper and lower surfaces. Examples of such devices and their methods of
20 manufacture are disclosed in the following US patents, the disclosures of which are incorporated
21 herein by reference: US 6,429,533; US 6,380,839; US 6,377,467, US 6,242,997; US 6,236,302;
22 US 6,223,423; US 6,172,591; US 6,124,781; US 6,020,808; and US 5,802,709.

23 At temperatures below a certain value, referred to generally as the critical or switching
24 temperature, PTC materials of the type referred to above exhibit a relatively low, constant
25 resistivity. However, as the temperature of the PTC material increases beyond the critical
26 temperature, the resistivity of the material sharply increases with temperature. When the
27 temperature of the material cools down below the critical or switching temperature, the
28 resistivity reverts to its low, constant value. This effect has been used in the production of
29 electronic PTC devices providing overcurrent protection in electrical circuits, where they are
30 generally placed in series with a load.

1 There is an on-going trend in the electronics industry toward miniaturization, and in
2 particular reduction of the physical size of the components. One way this has been achieved is
3 the introduction of surface mount technology (SMT) components. In SMT components, the
4 devices are soldered directly to the circuit boards, thus doing away with the space requirement
5 for leads on devices and corresponding holes in the circuit boards. Still, as with other electronic
6 applications, in SMT there is an on-going need to minimize the effective surface area or footprint
7 of the devices. However, the operational requirements of PTC devices limit the degree to which
8 the operational surface area of the PTC material can be reduced.

9 This need for an effective surface area based on the operational requirements of the
10 devices is a major limiting factor in the design of small SMT PTC devices. For example, to
11 maximize the effective surface area for a given footprint, the two electrical terminals for a PTC
12 device may be positioned at opposing ends of the device. While this facilitates the full use of the
13 surface area of the PTC material, the requisite soldering process occupies valuable space on a
14 printed circuit board (PCB), effectively increasing the footprint of the PTC device.

15 A known solution to this problem is to position the two electrical terminals on the
16 underside of the PTC device. This, however, requires that a connection be provided from the
17 upper foil electrode layer of the PTC device to a terminal on the underside. This connection
18 either significantly reduces the effective area of the PTC material or requires the use of a wrap
19 around connection, which adds cost. For example, in US 6,292,088 a PTC device is disclosed in
20 which an interconnection passes through the device. To prevent the interconnection shorting the
21 two metal layers, a section of one of the metal layers adjacent to the interconnection is removed
22 to provide an isolation barrier. However, the removal of this section significantly reduces the
23 effective surface area of the PTC device, as the area of the metal layer removed to provide
24 isolation equates approximately to the thickness of the PTC material. In addition, the area of
25 metal that has been isolated, and the corresponding region of PTC material, serves no other
26 purpose than to provide an electrical contact. US 6,377,467 discloses a PTC device having a pair
27 of terminals on the underside of device. The terminals are positioned on-top of an insulating
28 layer to isolate them from each other and also from underlying electrodes of the PTC material.
29 Each of the terminals of the pair are connected to a corresponding terminal on the top side of the
30 device by an interconnection. The interconnections also provide electrical connections to the
31 electrodes of the PTC material. However, to prevent the interconnections shorting the two

1 electrodes, a section of one of the metal electrodes adjacent to each interconnection is removed
2 to provide an isolation barrier. Thus the effective area of the PTC device is significantly reduced.

3 U.S. Patents 5,907,272 and 5,884,391 show examples of PTC devices in which the
4 connection from the upper foil layer to a terminal on the underside is provided by a wrap-around
5 conductor arrangement. This configuration makes an electrical connection by wrapping a
6 conductive layer around the PTC material rather than wasting surface area of the PTC material in
7 providing an interconnection. It is suggested however that the manufacturing methods of these
8 patents may be inefficient and costly.

9 Accordingly, there is a need for an improved SMT PTC device, and a method for
10 manufacturing it, in which the usable effective surface area of the PTC material within a given
11 footprint on a PC board is maximized, and in which connections required to connect the upper
12 electrode to the lower electrode use optimum area and at the same time do not reduce the
13 effective area of the PTC material.

14 SUMMARY OF THE INVENTION

15 In one aspect, the present invention provides a method of manufacturing an electronic
16 device from a structure comprising at least one layer of device material sandwiched between a
17 first layer of metal and a second layer of metal. The method comprises the steps of forming a
18 first aperture through the first layer of metal, the second layer of metal and the device material,
19 applying a first layer of insulating material to the first metal layer, insulating the walls of the first
20 aperture, providing a third metal layer on the first layer of insulating material, forming a second
21 aperture within the region defined by the first aperture, providing a first electrical
22 interconnection between the top and bottom surfaces of the through the second aperture,
23 creating an electrical interconnection between the third metal layer and the first metal layer,
24 selectively removing metal from the third metal layer to define first and second electrode areas,
25 wherein the first terminal includes the electrical interconnection created between the third metal
26 layer and the first metal layer and the second terminal includes the plated second aperture.

27 By using an insulated conductive channel to provide a path from one side of the device to
28 the other, the effective surface area of the active material may be maximized, since only the area
29 occupied by the channel is required to provide the interconnection between the upper and lower
30 surfaces of the device.

1 The method may comprise the further steps of applying a second layer of insulating
2 material on the second metal layer, and providing a fourth metal layer on the second layer of
3 insulating material in advance of forming the second aperture.

4 The step of insulating the walls of the first aperture may be performed at least in part by
5 the step of applying the first layer of insulating material to the first metal layer and/or by the step
6 of applying the second layer of insulating material to the first metal layer,

7 In advance of the application of the insulating layers, a third aperture may be formed
8 through the first metal layer, second metal layer and the at least one layer of device material
9 subsequent to which a fourth aperture may be formed within the region defined by the third
10 aperture. Whereupon the fourth aperture may be plated to provide a second electrical
11 interconnection between the top and bottom surfaces of the device.

12 Third and fourth terminals may be defined using an additional step of selectively
13 removing material from the fourth metal layer.

14 The first and third apertures may be formed at opposing ends of the device.

15 The method may include the initial step of defining singulation references in the first and
16 second layers of metal.

17 Advantageously, the steps of applying the first layer of insulating material to the first
18 metal layer and providing a third metal layer on the first layer of insulating material may be
19 performed in a single step by the application of a resin clad metal, optionally copper.

20 Similarly, the steps of applying the second layer of insulating material to the second
21 metal layer and providing the fourth metal layer on the second layer of insulating material may
22 be performed in a single step by the application of a resin clad metal, optionally copper.

23 Optionally, the structure comprising at least one layer of device material sandwiched
24 between a first layer of metal and a second layer of metal may be a multi layer structure
25 comprising alternating layers of device material and metal.

26 The method of manufacturing a device is particularly suitable for the manufacture of PTC
27 devices, and in which case the device material is a PTC material.

28 The structure comprising at least one layer of device material sandwiched between a first
29 layer of metal and a second layer of metal may be provided as a laminated sheet.

30 In another aspect of the invention, an electronic device is provided comprising a first
31 metal layer, a second metal layer and at least one layer of device material sandwiched between

1 the first metal layer and the second metal layer which function as electrodes for the device
2 material. A first terminal is provided for a first electrical connection to the device and
3 a second terminal is provided for a second electrical connection to the device,
4 wherein the first terminal is electrically connected to the first metal layer and the second terminal
5 is insulated from the first metal layer and electrically connected to the second metal layer by a
6 conductive channel which passes through and is insulated from the first metal layer and device
7 material. The conductive channel may be a metal plated channel.

8 The second terminal may be insulated from the first metal layer by a first layer of
9 insulating material. This first layer of insulating material may substantially cover the first layer
10 of metal.

11 A third layer of metal may be provided on the first layer of insulating material. This third
12 layer may be divided by an isolation area to provide the first terminal and the second terminal.

13 The device may further comprise a third terminal for providing a third electrical
14 connection to the device and a fourth terminal for providing a fourth electrical connection to the
15 device, wherein the fourth terminal is electrically connected to the second metal layer and the
16 third terminal is insulated from the second metal layer and electrically connected to the first
17 metal layer by a second conductive channel which passes through and is insulated from the
18 second metal layer and device material.

19 The second conductive channel may be a metal plated channel, which may be located at
20 one end of the device. Moreover, the first conductive channel and the second conductive channel
21 may be located at opposing ends of the device.

22 The second terminal may be insulated from the second metal layer by a second layer of
23 insulating material, which may substantially cover the second layer of metal.

24 The fourth terminal may be electrically connected to the second metal layer by an
25 interconnect formed through said second layer of insulating material.

26 The terminals of the device may be plated, optionally with nickel, copper and/or gold.
27 The insulating material may comprise a cured resin. The at least one layer of device material
28 may comprise alternating layers of device material and metal.

29 The device may be a PTC device and in which case the device material is a PTC material.

30 In another aspect of the invention a PTC device is provided comprising:
31 a first metal layer, a second metal layer and at least one layer of PTC material sandwiched

1 between the first metal layer and the second metal layer. A first terminal is provided as a first
2 electrical connection to the device and a second terminal is provided as a second electrical
3 connection to the device,
4 wherein the first terminal is electrically connected to the first metal layer and the second terminal
5 is electrically connected to the second metal layer by a conductive channel which passes through
6 and is insulated from the first metal layer and the at least one layer of PTC material.

7 In a further aspect of the invention, a method of manufacturing a matrix of electronic
8 devices from a structure comprising at least one layer of device material sandwiched between a
9 first layer of metal and a second layer of metal is provided. The method comprising the steps of
10 forming a first array of apertures through the first layer of metal, the second layer of metal and
11 the device material, applying a first layer of insulating material to the first metal layer,
12 insulating the walls of the first array of apertures, providing a third metal layer on the first layer
13 of insulating material, forming a second array of apertures such that each aperture of the second
14 array is positioned within the region defined by an aperture from the first array of apertures,
15 providing electrical interconnections between the top and bottom surfaces of the matrix through
16 the second array of apertures to create electrical interconnections between the third metal layer
17 and the first metal layer, selectively removing metal from the third metal layer to define first and
18 second terminals for each device of the matrix, wherein each first terminal includes an electrical
19 interconnection between the third metal layer and the first metal layer and each second terminal
20 includes an insulated electrical interconnection between the top and bottom surfaces of the
21 device.

22 The step of insulating the walls of the first array of apertures may be performed at least in
23 part by the step of applying the first layer of insulating material to the first metal layer,

24 The method may comprise the further steps of: applying a second layer of insulating
25 material on the second metal layer, and providing a fourth metal layer on the second layer of
26 insulating material in advance of forming the second array of apertures.

27 Advantageously, the step of insulating the walls of the first array of apertures may be
28 performed at least in part by the step of applying the second layer of insulating material to the
29 first metal layer.

30 The method may comprise the further steps of forming a third array of apertures, in
31 advance of the application of the insulating layers, through the first metal layer, second metal

1 layer and the at least one layer of device material, forming a fourth array of apertures within the
2 region defined by the third array of apertures, and providing electrical interconnections between
3 the top and bottom surfaces of the device through the fourth array of apertures.

4 The method may comprise the additional step of selectively removing material from the
5 fourth metal layer to define third and fourth terminals for individual devices in the matrix.

6 Each of the first array of apertures and each corresponding aperture of the third array of
7 apertures may be formed on opposing ends of the individual devices within the matrix.

8 As an initial step singulation references may be defined in the first and second layers of
9 metal.

10 Advantageously, the steps of applying a first layer of insulating material to the first metal
11 layer and providing a third metal layer on the first layer of insulating material may be performed
12 in a single step by the application of a resin clad metal, optionally copper.

13 Similarly, the steps of applying a second layer of insulating material to the second metal
14 layer and providing a fourth metal layer on the second layer of insulating material may be
15 performed in a single step by the application of a resin clad metal, optionally copper.

16 Optionally, the structure comprising at least one layer of device material sandwiched
17 between a first layer of metal and a second layer of metal may be a multi layer structure
18 comprising alternating layers of device material and layers of metal.

19 Where the device is a PTC device, the device material is a PTC material.

20 The method may comprise the additional step of joining a second matching matrix of
21 electronic devices to the matrix such that terminals of adjoining faces of each matrix are aligned
22 and electrically connected. As a final step, the devices may be singulated from the matrix.

23 As part of the singulation process, groups of two or more devices may be singulated
24 together as individual devices. In this case, they may be configured as SIP or DIP packages.

25 The device material may be a dielectric material.

26 In a further aspect of the invention, a matrix of electronic devices is provided comprising
27 a first metal layer, a second metal layer and at least one layer of device material sandwiched
28 between the first metal layer and the second metal layer which function as electrodes for the
29 device material. First and second arrays of terminals provide electrical connections to individual
30 devices of the matrix, wherein the first array of terminals are electrically connected to the first
31 metal layer and the second array of terminals are insulated from the first metal layer and

1 electrically connected to the second metal layer by conductive channels which pass through and
2 are insulated from the first metal layer and device material. The conductive channels may be
3 metal plated channels. The second array of terminals may be insulated from the first metal layer
4 by a first layer of insulating material, which may substantially cover the first layer of metal.

5 A third layer of metal may be disposed on the first layer of insulating material, here said
6 third layer is divided by an array of isolation areas to provide the first array of terminals and the
7 second array of terminals.

8 Third and fourth arrays of terminals may also provide electrical connections to
9 individual devices. Moreover, the fourth array of terminals may be electrically connected to the
10 second metal layer, and the third array of terminals may be insulated from the second metal layer
11 and electrically connected to the first metal layer by a second array of conductive channels which
12 pass through and are insulated from the second metal layer and material.

13 The second array of conductive channels may comprise metal plated channels. The
14 second array of terminals may be insulated from the second metal layer by a second layer of
15 insulating material which may substantially cover the second layer of metal.

16 The fourth array of terminals are electrically connected to the second metal layer by
17 interconnects formed from through said second layer of insulating material.

18 Each of the array of second conductive channels is provided at an end of each device of
19 the matrix moreover each of the array of first conductive channels and second conductive
20 channels may located at opposing ends of each device of the matrix.

21 The terminals of the matrix may be plated, optionally with nickel, copper and/or gold.

22 The insulating material may comprise a cured resin.

23 The at least one layer of device material may comprise alternating layers of device
24 material and layers of metal. Where the devices of the matrix are PTC devices the device
25 material is a PTC material.

26 The invention extends to a stacked matrix comprising at least two matrices of the type
27 described which are stacked on top of each other and in which corresponding terminals are
28 electrically connected.

29 The above mentioned advantages of the present invention, as well as others, will be more
30 readily appreciated from the detailed description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described with reference to the drawings in which:

FIG. 1 is a cross-sectional view of a portion of a laminated sheet from which the present invention is made;

FIG. 2 is a top plan view of the sheet portion shown in FIG. 1, after the step of forming a first array of apertures in the sheet;

FIG. 3 is a cross-sectional view taken along line X – X of FIG. 2;

FIG. 4 is a cross-sectional view, similar to that of FIG. 3, showing the result of a subsequent step in the process of the invention;

FIG. 5 is a cross-sectional view, similar to that of FIG. 4, showing the result of the next step in the process of the invention;

FIG. 6 is a cross-sectional view, similar to that of FIG. 5, showing the result of the next step in the process of the invention;

FIG. 7 is a cross-sectional view, similar to that of FIG. 6, showing the result of the next step in the process of the invention;

FIG. 8 is a cross-sectional view, similar to that of FIG. 7, showing the result of the next step in the process of the invention;

FIG. 9 is a cross-sectional view, similar to that of FIG. 8, showing a finished symmetrical PTC device according to the invention;

FIG. 10 is a cross-sectional view of a non-symmetrical embodiment of the PTC device of the invention;

FIG. 11 is a cross-sectional view of a multi-layer PTC device according to the invention;

FIG. 12 is a top view of an embodiment of the invention comprising four individual PTC devices packaged as a single multi-device component;

FIG. 13 is a top view of a SIP embodiment of the invention comprising an individual device;

FIG. 14 is a schematic representation of a line protection circuit suitable for implementation by devices of the invention;

FIG. 15 is a top view of an implementation of the schematic circuit of FIG. 14 according to the invention;

FIG. 16 is a side view of a matrix of devices;

1 FIG. 17 is a side view of the matrix of FIG. 16, illustrating a further step in a process of
2 the invention;

3 FIG. 18 is a side view of the matrix of FIG. 17, illustrating a further step in a process of
4 the invention; and

5 FIG. 19 is a side view of a singulated device formed from the matrix of FIG 18.

6 DETAILED DESCRIPTION OF THE INVENTION

7 Referring now to the drawings, FIG. 1 illustrates a portion of a laminated sheet 10 that
8 may be provided as an initial step in the process of manufacturing an electronic device in
9 accordance with the present invention. The sheet 10 comprises two layers of metal foil 12, 14
10 and a region of active device material, for example conductive polymer PTC material 16.
11 Specifically, the exemplary laminated sheet 10 shown comprises a layer of conductive polymer
12 PTC material 16 sandwiched between a first or lower layer of metal foil 12 and a second or
13 upper layer of metal foil 14.

14 The layer of conductive polymer PTC material 16 may comprise any suitable PTC
15 material, including for example any suitable conductive polymer composition. An example of a
16 suitable conductive polymer composition would be high density polyethylene (HDPE) into
17 which is mixed an amount of carbon black that results in the desired electrical operating
18 characteristics. An example of such a mixture is disclosed in WO97/06660, the disclosure of
19 which is incorporated herein by reference. The metal layers 12, 14 may comprise any suitable
20 metal, typically provided as a thin foil, with copper being preferred, although other metals, such
21 as nickel and aluminum along with a number of alloys are also acceptable.

22 The laminated sheet 10 may be formed by any of several suitable processes that are well
23 known in the art, as exemplified by the above referenced publication WO97/06660.

24 The present invention, in one aspect, is a manufacturing method or process comprising a
25 series of processing steps performed upon the laminated sheet 10 to produce a matrix comprising
26 a plurality of electronic devices. These steps will now be explained with reference to FIGS. 2
27 through 13.

28 An advantageous first step in the exemplary process is the definition, in the sheet 10, of
29 an array of singulation lines (not shown), that define a matrix of sheet sections 23, 24, 25 (FIG.
30 2), each of which will be formed into an individual device, as described below. The fully formed

individual devices will, at the end of the process described below, be singulated from the matrix along the singulation lines. The singulation lines may comprise a rectangular (X-Y) grid of lines formed by the selective removal of metal from the first layer 12 and/or second layer 14 of metal. The selective removal of this metal may be by any suitable process including standard printed circuit board assembly techniques employing photo-resist and etching methods well known in the art.

After the formation of the singulation lines, the next step in the process, illustrated in FIG. 2, is the formation of a first array of apertures 30, 32 in the laminated sheet 10. Each section 24 of the sheet to be singulated should have at least one aperture or share an aperture with an adjoining section. Any suitable PCB process including drilling, laser drilling, etching and punching may form the apertures 30, 32. The apertures provide openings from the top surface (upper metal layer 14) of the laminated sheet through to the lower surface (lower metal layer 12) of the laminated sheet.

The remaining steps of the process will be described with reference to this single section 24 defining an individual unit or device. It will be appreciated, however, that the subsequent process steps are intended to produce a matrix of devices from the laminated sheet 10 as a whole, and that the individual unit is only shown for clarity. In practice the individual unit is not singulated from the matrix until substantially all of the process steps have been completed.

As illustrated in FIG. 3, each of the apertures 30, 32 passes through the first metal layer 12, the layer of PTC material 16 and the second metal layer 14; i.e., the apertures 30, 32 define channels from the bottom surface of the laminated sheet 10 to the top surface. As illustrated in FIG. 4, after the apertures 30, 32 have been formed, a first layer of insulating material 40 is formed on or applied to the surface of the first layer 12 of metal. Similarly, a second layer of insulating material 42 is formed on or applied to the surface of the second layer 14 of metal. The insulating material is selected to ensure that it will flow into and substantially fill the apertures 30, 32, either directly or under pressure. These steps ensure that regions 44, 46 of insulating material substantially fill the apertures 30, 32. Although it is preferable that the apertures 30, 32 are replaced/filled by regions of insulating material, the primary purpose of the insulating material is to provide an insulating barrier to the walls defining the apertures 30, 32, i.e. the exposed edge surfaces of the first metal layer 12, the PTC material 16, and the second metal layer 14 defining the apertures. It will also be appreciated that a separate process may be used to

1 provide an insulating barrier to the walls of the apertures distinct from the application of the first
2 and second layers of insulation, i.e. using a separate process to fill the apertures 30, 32 with
3 insulating material. However, this is a less preferred alternative as it introduces an additional
4 step to the process.

5 The insulating material may be any suitable material, including plastic (e.g. epoxy resin).
6 Fibers (e.g. glass) may be included within the insulating material to provide mechanical strength.
7 In particular, the material referred to generally in the PCB industry as pre-preg, is an ideal
8 insulating material. A preferred specific type of pre-preg for this application comprises a 1080
9 glass fabric (fiber glass) filled with a 62% resin content.

10 A third metal layer 48 is formed on or applied to the first layer of insulating material 40.
11 Similarly, a fourth metal layer 50 is formed on or applied to the second layer of insulating
12 material 42, resulting in the structure shown in FIG. 4. Suitable materials for the metal layers 48,
13 50 may include foils of copper, nickel, aluminum, and a number of alloys thereof. Such foils
14 may be laminated or bonded to the respective insulating layers 40, 42. Deposition processes
15 such as plating may also provide the third and fourth metal layers.

16 Advantageously, the steps of applying the layers of insulating material and metal may be
17 combined into a single step through the use of resin clad metal materials, for example resin clad
18 copper (RCC). The use of RCC allows the metal and insulating layers to be applied
19 concurrently. A suitable RCC material would be a 1080 glass fabric impregnated with a 62%
20 resin content and clad with copper. The adherence of the first and second insulating layers 40, 42
21 to the first and second metal layers 12, 14 respectively may be achieved by conventional PCB
22 techniques, familiar to those skilled in the art.

23 After the insulating layers 40, 42 and additional metal layers 48, 50 have been applied/
24 formed, a second array of apertures 60, 62 is defined/formed in the laminated sheet 10. Any
25 suitable process including conventional drilling or laser drilling techniques may form these
26 apertures. Each aperture 60, 62 of this second array is suitably formed within the boundary
27 defined by a corresponding aperture 30, 32 of the first array of apertures, as illustrated in FIG. 5.
28 The diameter of each of the apertures 60, 62 of the second array of apertures is less than the
29 diameter of the apertures 30, 32 of the first array of apertures. The result of using smaller
30 diameter apertures for the second array is that each of the apertures 60, 62 of the second array
31 provides an insulated channel between the upper and lower surfaces of the laminated sheet 10

1 which is insulated from the first and second layers of metal 12, 14 and the layer PTC material 16.
2 The insulating barrier 44, 46 for the channels is provided by the insulating material from the first
3 and second layers of insulating material which substantially filled the first array of apertures 30,
4 32.

5 The next step in the process, illustrated in FIG. 6, is to provide conductive paths between
6 the third 48 and fourth 50 metal layers using each of the insulated channels provided by the
7 apertures 60, 62 in the second array. That is, an array of external electrical interconnections 66,
8 68 is formed between the top and bottom surfaces of the sheet 10. These interconnections may
9 be provided by any suitable process, including for example, plating (i.e. provision of a plated
10 through-hole via) or the insertion of a conductive material. Examples of suitable conductive
11 materials may include conductive epoxy or solder paste. A suitable plating process is an electro-
12 plating process. Suitably, in an electro-plating process, the third metal layer 48 is used as a first
13 electrode and the fourth metal layer 50 is used as a second electrode for the plating process. The
14 result, as shown in FIG. 6, is the provision of a pair of external conductive interconnections 66,
15 68 between the top and bottom surfaces of the laminated sheet 10 on opposite ends of each unit
16 or section 24.

17 After forming the external conductive interconnections 66, 68, a first array of internal
18 interconnections is formed between the fourth metal layer 50 and the second metal layer 14.
19 Similarly, a second array of internal interconnections is provided between the third metal layer
20 48 and the first metal layer 12. These internal interconnections will provide conductive paths
21 between the first metal layer 12 and the third metal layer 48, and between the second metal layer
22 14 and the fourth metal layer 50. As shown in FIG. 7, before an electrical connection between
23 the first and third metal layers may be provided, a first array of openings or "micro-vias" 70 is
24 formed from the lower surface of the sheet (the third metal layer 48) through to the surface of the
25 first metal layer 12, while a second array of blind openings or "micro-vias" 72 is formed from
26 the upper surface of the of the sheet (the fourth metal layer 50) through to the surface of the
27 second metal layer 14. Suitable methods for forming these blind openings or micro-vias 70, 72
28 include laser drilling and etching.

29 Once the micro-vias 70, 72 have been formed, the internal electrical interconnections
30 may be established through the micro-vias by disposing conductive material within them. The
31 preferred method of providing the conductive material is a conventional plating process, such as

1 electroplating or electroless plating. The electrical connections may also be provided by
2 inserting a conductive material, for example conductive epoxy or solder paste, into the micro-
3 vias 70, 72. Assuming a suitable plating process is used, FIG. 8 shows a lower plating layer 80
4 and an upper plating layer 82 deposited over the third and fourth metal layers 48, 50 respectively.
5 The plating layers 80, 82 fill the micro-vias 70, 72, respectively, forming lower and upper
6 internal conductive interconnections 84, 86, respectively, within the micro-vias 70, 72. As a
7 result of this plating, a continuous path of conductive metal is formed from the first metal layer
8 12, through the lower internal interconnection 84, the lower plating layer 80, the first external
9 interconnection 66, the upper plating layer 82, and the second external interconnection 68. A
10 conductive path is also established between the second metal layer 14 to the upper plating layer
11 82 through the upper internal interconnection 86, as shown in FIG. 8.

12 At this point it is necessary to form two separate, electrically isolated conductive paths so
13 as to provide a first terminal that electrically connects the first metal layer 12 to the upper plating
14 layer 82, and a second terminal, electrically isolated from the first terminal, that electrically
15 connects the second metal layer 14 to the lower plating layer 12. The formation of the first and
16 second terminals for subsequent use as connection points for the PTC devices is shown in FIG 9.
17 The lower plating layer 80 and the third metal layer 48 are masked and selectively etched away
18 to form lower isolation areas 97 on the lower surface of the sheet 10 that are devoid of metal and
19 that divide the third metal layer 48 and the lower plating layer 80 of each unit 24 into separate
20 first and second lower terminal pads 90, 92 (i.e. the areas at each end of the unit where the third
21 metal layer has not been removed). This selective removal may be performed by any suitable
22 process, including, for example, standard photo-resist and etching techniques. Similarly, the
23 upper plating layer 82 and the fourth metal layer 50 are masked and selectively etched away to
24 form upper isolation areas 99 on the upper surface of the sheet that are devoid of metal and that
25 divide the fourth metal layer 50 and the upper plating layer 82 of each unit 24 into separate first
26 and second upper terminal pads 94, 96.

27 The two lower terminal pads 90, 92 are suitably positioned in regions adjacent the
28 opposite ends of the device or unit 24, and they are respectively connected to the corresponding
29 upper terminal pads 94, 96 by the respective insulated conductive channels that respectively form
30 the external interconnections 66, 68. Furthermore, the first metal layer 12 is electrically
31 connected to the first lower terminal pad 90 by the lower internal interconnection 84, while

1 second metal layer 14 is electrically connected to the second upper terminal pad by the upper
2 internal interconnection 86. Thus, a first terminal is formed, comprising the first lower terminal
3 pad 90, the first external interconnection 66, and the first upper terminal pad 94, which terminal
4 provides electrical connection to the first metal layer 12, which thereby forms a first electrode.
5 Likewise, a second terminal is formed, comprising the second lower terminal pad 92, the second
6 external interconnection 68, and the second upper terminal pad 96, which terminal provides
7 electrical connection to the second metal layer 14, which thereby forms a second electrode. This
8 results in a symmetrical PTC device 24 which, when singulated from the sheet 10 (i.e., the
9 overall matrix of devices), may used directly as an SMT PTC device. Suitable techniques for
10 singulation are well known in the art and include routing, guillotining, dicing, punching, laser
11 cutting and scouring.

12 In particular, the process described above produces a matrix comprising a plurality of
13 laminar PTC devices which may be singulated from the original matrix. Each of the PTC
14 devices comprises a first or lower electrode 12 formed from the first metal layer 12, and a second
15 or upper electrode 14 formed from the second metal layer 14. A layer of PTC material 16 is
16 sandwiched between these first and second electrodes 12, 14. The first electrode 12 is
17 substantially covered by a first layer 40 of insulating material. Similarly, the second electrode 14
18 is substantially covered by a second layer of insulating material 42. A third metal layer 48 is
19 provided on the first insulating layer 40. The third metal layer 48 is divided to form first and
20 second lower terminal pads 90, 92 on the underside of the device. The two lower terminal pads
21 are positioned in regions adjoining opposing ends of the PTC device. The first lower terminal
22 pad 90 is connected to the first electrode 12 by the first internal interconnection 84 that passes
23 through the first layer of insulating material 40. The second lower terminal pad 92 is separated
24 from the first lower terminal pad 90 by the lower isolation area 97 where the third metal layer 48
25 has been selectively removed, and it is insulated from the first electrode 12 by the first layer of
26 insulating material 40.

27 Likewise, the fourth metal layer 50 is divided by the upper isolation area 99, where metal
28 has been selectively removed, to provide the first and second upper terminal pads 94, 96. The
29 first and second upper terminal pads 94, 96 are positioned in regions adjoining opposing ends of
30 the PTC devices. Suitably, the positioning of the first and second upper terminal pads 94, 96
31 corresponds directly to positioning of the first and second lower terminals 90, 92, respectively.

1 In other words, the first upper terminal pad 94 is formed on the opposing side of the PTC device
2 to the first lower terminal pad 90, and the second upper terminal pad 96 is formed on the
3 opposing side of the PTC device to the second lower terminal pad 92.

4 The second upper terminal pad 96 is connected to the second electrode 14 by the second
5 or upper internal interconnection 86 that passes through the second layer of insulating material
6 42. The first upper terminal pad 94 is separated from the second upper terminal pad 96 by the
7 upper isolation area 99 where metal has been selectively removed, and it is insulated from the
8 second electrode 14 by the second layer of insulating material 42.

9 The first lower terminal pad 90 is electrically connected to the first upper terminal pad 94
10 by the first conductive external interconnection 66, which passes through and is insulated from
11 the first and second electrodes 12, 14 and the layer of PTC material 16. Similarly, the second
12 lower terminal pad 92 is connected to the second upper terminal pad 96 by the second conductive
13 external interconnection 68, which passes through and is insulated from the first and second
14 electrodes 12, 14 and the layer of PTC material 16. It will be appreciated that the resulting PTC
15 device comprises two paired arrangements of terminal pads on opposing sides of the PTC device.
16 The effective resistance between the terminal pads in each pair is that of the PTC material (as
17 contact and interconnect resistances are small in comparison, particularly when the PTC material
18 is in a tripped state).

19 By using insulated conductive channels to provide the external interconnections 66, 68
20 from one side of the PTC device to the other, the effective surface area of the PTC material
21 utilized by the device may be maximized.

22 The above described process results in a symmetrical PTC device that facilitates easy
23 placement without the need for correct orientation of the device beforehand.

24 Of particular advantage is that the PTC devices are manufactured using techniques that
25 are commonplace in the reasonably low cost manufacturing environment of the PCB industry.
26 The above described process has been described with reference to the production of a
27 symmetrical PTC device having a single layer of PTC material. It will be appreciated that
28 further embodiments are possible. For example, a non-symmetrical device, i.e. where the device
29 will only function correctly when placed with the underside down, may be provided by the
30 omission of a number of the steps in the above described process and correspondingly the
31 omission of a number of the features in the above described PTC device. In particular, the

1 requirement for a second external interconnection provided by an insulated channel, a fourth
2 metal layer and a second layer of insulating material may be obviated as illustrated in the
3 exemplary structure of FIG. 10. In particular, a non-symmetrical laminar PTC device may be
4 provided, comprising a first laminar metal electrode 12 and a second laminar metal electrode 14.
5 A layer of PTC material 16 is sandwiched between these first and second electrodes 12, 14. The
6 first electrode 12 is substantially covered by a first layer of insulating material 40. A third layer
7 of metal 48 is provided on the first layer of insulating material 40. The over-plated third layer of
8 metal 48 is divided by an isolation area 97 to form first and second lower terminal pads 90, 92.
9 The two terminal pads are positioned in regions adjoining opposing ends of the PTC device. The
10 first terminal pad 90 is connected to the first electrode 12 by an internal conductive
11 interconnection 84 formed through an opening or micro-via that passes through the first layer of
12 insulating material 40. The second terminal pad 92 is separated from the first terminal pad 90 by
13 the isolation area 97 where the over-plated third metal layer 48 has been selectively removed,
14 and it is insulated from the first electrode 12 by the first layer of insulating material 40.

15 The second terminal pad 92 is electrically connected to the second electrode 14 by a
16 conductive channel that forms an external interconnection 68, formed as described above (with
17 modifications to account for the absence of the second insulating layer and fourth metal layers),
18 which passes through and is insulated from the first and second electrodes 12, 14 and the layer of
19 PTC material 16.

20 A further exemplary embodiment, as illustrated in FIG. 11, employs multiple layers of
21 PTC material in the production of the PTC device instead of a single layer of PTC material. In
22 this device, the single layer of PTC material sandwiched between two layers of metal
23 (electrodes) is replaced by a laminar structure comprising three electrodes 120, 122, 124
24 interleaved with two layers of PTC material 126, 128. The remaining features and the method of
25 manufacture are substantially unchanged.

26 This further embodiment in effect provides two PTC devices in series, with the middle
27 electrode acting as a common electrode to the first device, comprising the top electrode and top
28 layer of PTC material, and the second device comprising the bottom electrode and bottom layer
29 of PTC material. It is believed that this multilayer structure provides a series combined PTC
30 device having a higher breakdown voltage than would be achievable with a single PTC device.

1 An exemplary multi device package configuration is illustrated in FIG. 12, comprising a
2 plurality of devices, of the type illustrated in FIGS. 9, 10 or 11, which may be fabricated in a
3 matrix using the processes described above. The exemplary package 100 shown comprises four
4 individual devices, although the exact number of devices can be altered depending on
5 circumstances. Each of the individual PTC devices in the package 100 has pairs of terminals
6 provided on the underside of the package 100 adjacent to the insulated plated channels 194a,
7 194b; 195a, 195b; 196a, 196b, 197a, 197b to which electrical connections may be made. The
8 package 100 may readily be structured or configured to resemble an integrated circuit structure
9 for subsequent use by pick and place machines. Apart from appropriately dimensioning the
10 package 100 and positioning the plated channels to represent appropriate IC sizing and
11 connections, additional features may be included during the manufacturing process. For
12 example, a notch 190 may be provided in the top center of the package 100 to identify the
13 position of the top of the device. Similarly, a small dot 192 may be provided in the top left hand
14 corner of the package to identify the top left hand corner of the resulting device. These
15 additional features may be provided using conventional PCB techniques including etching as
16 integral steps within the manufacture of the matrix described above before singulation.

17 The resulting IC type device may be readily modified for use as a dual in-line package
18 (DIP) by appropriate fixing of a lead frame.

19 Although DIP packages are popular, in circumstances where board space is at a premium,
20 single in-line packages (SIP) are preferred. The present invention may be readily adapted for use
21 as a SIP package by providing paired terminals for connecting to each PTC device along one side
22 of the package rather than on opposing sides of the device, for example as shown in the
23 embodiment of FIG 13. In particular, as shown, a SIP package 175 has two terminals 170, 171,
24 with each terminal connecting to a laminar electrode of a PTC device encapsulated within the
25 device. The two terminals 170, 171 are arranged along the same device edge. Plated through-
26 hole external interconnections 172, 173 (formed prior to singulation from a matrix structure
27 described above) provide electrical connections between the top and bottom surfaces of the
28 terminals. As described previously, the through-hole interconnections 172, 173 are in effect
29 insulated conductive channels that provide external interconnections that pass through the PTC
30 material. One of the terminals 170 connects with a first laminar electrode by means of a first
31 blind micro-via 177 (as previously described) on the top surface of the device, whereas the other

terminal 171 connects with the second laminar electrode by means of a second blind micro-via 179 (shown in dashed outline) on the bottom surface of the device. The component may be used as a leaded device by attachment of a lead frame along the edge with the terminals. In either case, the component is not limited to single devices, and it will be appreciated that a SIP component may be manufactured having a plurality of devices, with each device having two terminals disposed along an edge of the component. Moreover, it will be appreciated that the exact number of PTC devices for a particular component is decided by the number of PTC devices grouped together as a single component during singulation of the matrix described above. However, to prevent cross effects between adjoining devices, separation of the electrodes in the first and second metal layers is required.

Depending on the application, the individual characteristics of the devices may be equivalent or different. Different characteristics may be achieved by having differently sized electrodes, which may be effected at the previously described stage of defining singulation references.

As the PTC devices described herein are manufactured using conventional PCB techniques, the resulting devices may be used as miniature printed circuit boards onto which further circuit protection devices, for example a battery charge controller or an over-voltage protection device, such as a gas discharge tube, a thyristor or a metal oxide varistor (MOV) may be fixed, for example by direct soldering to the terminals, to provide a circuit protection module. An exemplary input protection circuit is shown in FIG. 14, comprising a PTC device 210 providing over-current protection, in series with an incoming line 200 followed by an over-voltage protection device 214, for example a thyristor, MOV, or gas discharge tube (GDT), in parallel with the outputs 204. The circuit of FIG. 14 may be manufactured by singulating a device from the previously described matrix to provide a PTC device having an input terminal 200 on one side of the device and an output terminal 204 on the opposing side of the device. A track may also be provided in the same process used to define the terminals to provide a direct electrical connection between the second input line 202 and the output 206.

The circuit of FIG. 14 may be packaged as a component 240 of the type illustrated in FIG. 15. The top surface of the component 240 is suitably configured, as shown in FIG. 15, such that the output terminals on the top surface of the device are configured as terminal pads 220, 222 to which the voltage protection device 214 is electrically connected. The voltage protection

1 device 214 may be fixed to the pads 220, 224 by means such as pre-placed solder paste (which
2 may be then reflowed) or a conductive epoxy. The resulting component 240 may be used as an
3 SMT line protection device, with the terminals underlying the device (or plated channels\notches
4 at the sides) providing SMT connection points. Additionally, as described above, suitable device
5 markings may be included to aid orientation of the device. For example, a notch 218 may be
6 provided in the top center of the component 240 to identify the top of the component. Similarly,
7 a small dot 216 may be provided in a pre-selected corner of the component 240 for orientation
8 purposes.

9 A drawback of existing PTC devices is that the effective area of the PTC material limits
10 the trip currents of the devices. However, as circuit board space is generally at a premium,
11 designers are reluctant to use devices having large device footprints. One solution to this
12 problem is to provide PTC devices in a parallel configuration using a multilayer device
13 construction. There has been a constant effort in the art to reduce the costs and to increase the
14 efficiencies of manufacturing such multilayer devices.

15 The matrix construction of the present invention facilitates a simple and efficient method
16 of providing two or more devices in parallel in a quasi-multilayer construction. A side view of a
17 section of a matrix of devices (of the symmetrical type shown in FIG. 9) is illustrated in FIG. 16.
18 (The internal construction of the device is not shown for ease of explanation, with the vertical
19 dashed lines representing points along which devices would be singulated equating to the
20 locations of the insulated plated through-hole external interconnections of FIG. 9). Each of the
21 individual devices of the matrix has four terminals defined to provide device symmetry when
22 singulated. The method commences with the placing of a first matrix of devices 120 in a suitable
23 jig or fixture (not shown). Solder paste 126 or other conductive fixing/adhesive material (e.g.
24 conductive glue) is applied to the terminal areas 124 on the top surface of the matrix as shown in
25 FIG. 17. A second matrix of devices 128 having a matching arrangement of terminals areas 130
26 on its underside is then placed on top of the first matrix as shown in FIG. 18. In the case of using
27 solder paste, the entire arrangement is then placed in a reflow oven to cause the solder paste to
28 flow. When cooled the, the two matrices are held together in a double-decked or duplicate
29 matrix structure by the solder material, which electrically connects the terminals areas of the two
30 matrices. It will be appreciated that when the resulting duplex matrix is singulated, the
31 singulated devices, as shown in FIG. 19, are in effect two devices 136, 138 connected in parallel

1 with the terminals 140, 142 on the upper surface of the top device providing one pair of terminals
2 and the terminals on the lower surface of the bottom device providing a corresponding pair of
3 terminals 144, 146 on the bottom surface. Each of the top terminals 140, 142 is electrically
4 connected to its respective bottom terminal 144, 146 by respective insulated plated channels (as
5 described previously and shown in dashed outline in FIG. 19) in cooperation with the terminals
6 124, 130 and solder material 126. This method of manufacturing devices in parallel is not
7 limited to the use of two matrices, several matrices may be joined concurrently. However, as the
8 number of matrices increases, practical difficulties arise in causing the solder paste to reflow
9 correctly. This difficulty may be overcome if a conductive epoxy or other material is used in
10 place of the solder paste.

11 Although the present invention has been described with reference primarily to an active
12 material of the PTC type, it will be appreciated that the manufacturing process of the present
13 invention may be advantageously applied to other active polymer materials and PTC materials
14 and also to other materials including dielectrics, resistive, magnetic and semiconductor materials.

15 Although the present invention has been described with reference to commencement of
16 manufacture from a laminated sheet of electronically active (e.g. PTC) material sandwiched
17 between a first layer of metal and a second layer of metal, the method may commence with a
18 layer of electronically active (e.g. PTC) material upon which metal foils may be placed, or metal
19 layers deposited (e.g. by plating) as part of the manufacturing process described herein.